Chapter 4 The Geomagnetic Field

A Introduction

During the past three decades observations have shown that magnetic fields exist throughout the observable universe. We have actually observed naturally occurring magnetic fields ranging from 10^{-10} T to 10^{2} T and there are speculations that fields as high as 10^{8} T may exist in neutron stars.

In addition to the observational data we also have a good start on what is believed to be a general theory for generation or rather amplification of large scale magnetic fields. The theory presumes the existence of large, electrically conducting objects which rotate and have internal energy sources. We are reasonably sure that both the geomagnetic and solar magnetic fields are maintained by this magneto hydrodynamic process.

Looking at the earth as an example of a planetary system, we recognize two force fields (a) the gravitational field without which there would be no earth (b) the magnetic field both within and around the earth. The most convincing way to see how our ideas about the geomagnetic field have changed in the last 30 years is shown in Figure 4.1 which shows excerpts from three textbooks published in 1951, 1960 and 1971 respectively.

1 Constituents of the Geomagnetic Field:

We usually consider the geomagnetic field to be composed of a Main Field whose shape is approximately dipolar and whose time variations are on the order of years or longer. To a first approximation we describe the field as being generated by a fictitious dipole near the center of the earth. Both the magnitude and the orientation of this dipole undergo slow time variations (secular variations) which give rise to the well known gradual changes of the geomagnetic field components.

Superimposed on this quasistatic, quasidipole field are small fluctuations having periods of days or less. The source of these fluctuations are generally exterior to the earth and while their amplitude is small ($\Delta B / B \lesssim 0.01$) they are of considerable interest both from a geophysical and an applications point of view.

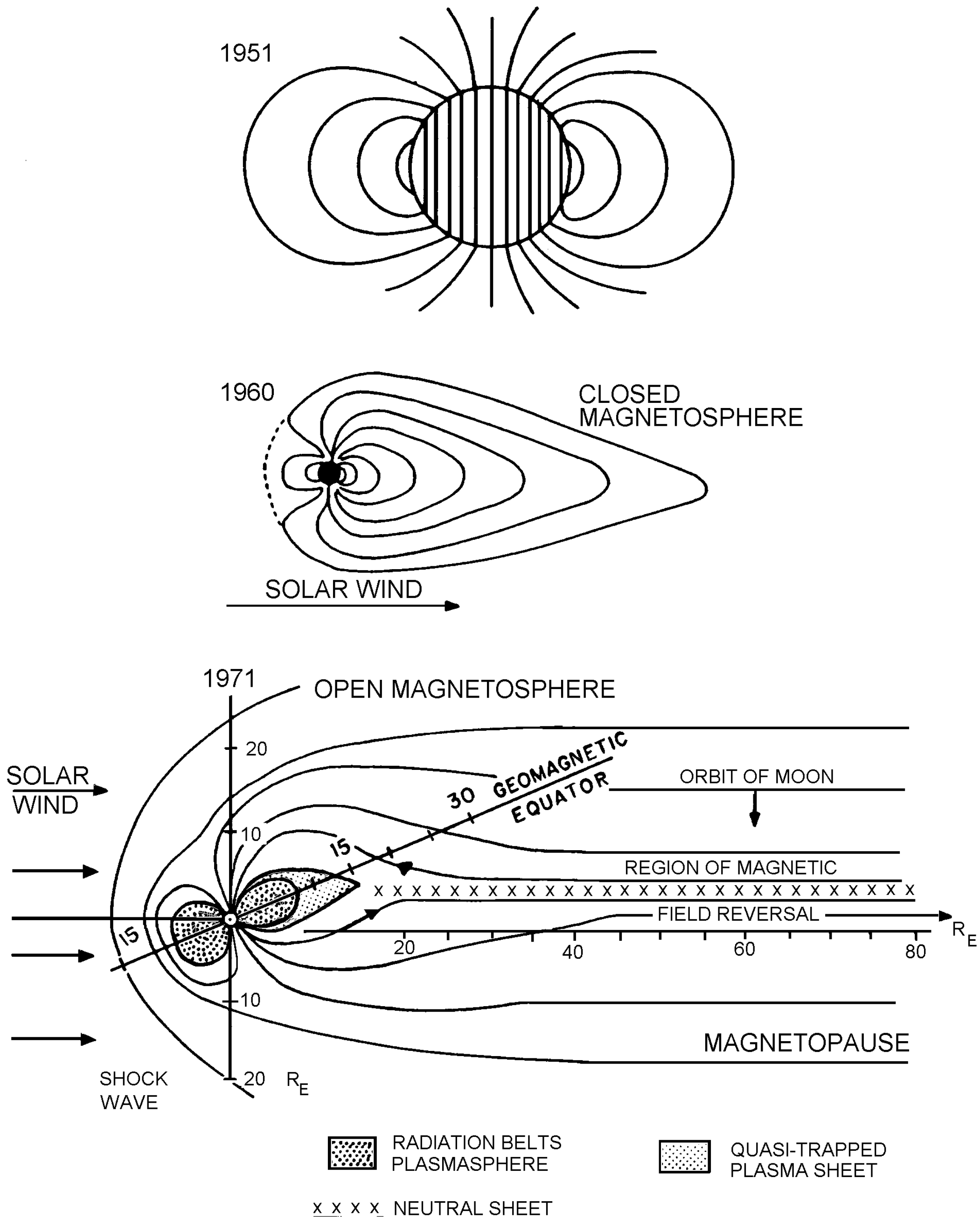

1951
1960
CLOSED
MAGNETOSPHERE
SOLAR WIND
1971
OPEN MAGNETOSPHERE
SOLAR
WIND
20
10
-10
20
30 GEOMAGNETIC
EQUATOR
ORBIT OF MOON
15
REGION OF MAGNETIC
X X X X X X X X X X X X X X X X X X X X X X X X X X X X X
FIELD REVERSAL
R
E
20
40
60
80
15
MAGNETOPAUSE
SHOCK
WAVE
RADIATION BELTS
PLASMASPHERE
QUASI-TRAPPED
PLASMA SHEET
X X X X NEUTRAL SHEET

Figure 4.1

B Main Geomagnetic Field

1 The Dipole Field

The most elementary description of the earth's magnetic field at and above the surface is modeled after the field of a small current loop, i.e., a terrestially centered magnetic dipole whose axis is tilted at an angle of approximately 11.5° with respect to the spin axis of the earth.

The sense of the field lines is from the southern geographic hemisphere toward the northern hemisphere as indicated in Figure 4.2. The magnitude and direction of the geomagnetic field vector at any point on the surface and at points above the surface out to a few earth radii can be obtained to an accuracy of about 10% using the following expressions for the field components of a dipole field in spherical coordinates.

$$B_r = \frac{\mu_0}{4\pi} \frac{2m\cos\theta}{r^3}$$

$$B_\theta = \frac{\mu_0}{4\pi} \frac{m\sin\theta}{r^3} \qquad \text{(Eqn. 4.1)}$$

$$B_\phi = 0$$

where:

$\mu_o = 4\pi \times 10^{-7}$ (Henry / meter)

m = Magnetic Dipole moment of the earth (8.1×10^{22} m^2A)

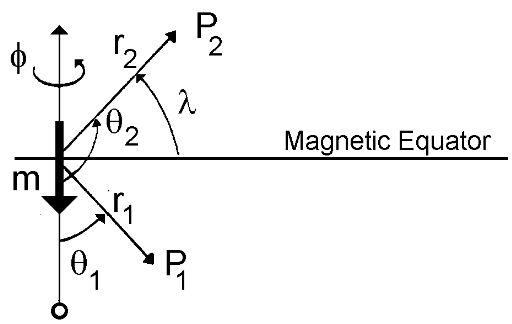


Figure 4.2. Coordinate system conventions for the earth's magnetic field.

It is often convenient to use the magnetic latitude λ (indicated in the sketch) rather than the polar angle θ. We note that in general

$\theta = \lambda + \pi/2$ where $\lambda > 0$ in Northern Hemisphere

$\lambda < 0$ in Southern Hemisphere

Hence $\sin\theta = \cos\lambda$ and $\cos\theta = -\sin\lambda$, and we can also write the field components as

$$B_r = -\frac{\mu_o}{4\pi}\frac{2m\sin\lambda}{r^3}$$

$$\text{(Eqn. 4.2)}$$

$$B_\lambda = \frac{\mu_o}{4\pi}\frac{m\cos\lambda}{r^3}$$

We can also calculate the magnitude of the $\vec{B}$ vector:

$$B^2 = B_r^2 + B_\theta^2 = \left(\frac{\mu_0 m}{4\pi r^3}\right)^2 \left(4\cos^2\theta + \sin^2\theta\right)$$

or (Eqn. 4.3)

$$B = \frac{\mu_0 m}{4\pi r^3}\sqrt{1+3\cos^2\theta} = \frac{\mu_0 m}{4\pi r^3}\sqrt{1+3\sin^2\lambda}$$

Figure 4.3 shows the general shape of the dipole field. Note that the lines emerge from the earth in the Southern Hemisphere so that the pole located in Antarctica should really be called the geomagnetic North Pole. But it was felt that this confused everybody and it is called the GM South Pole.

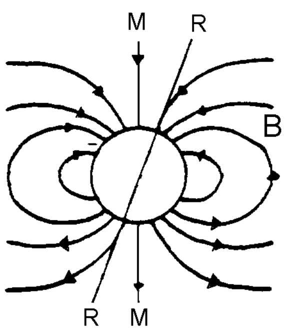


Figure 4.3 a) An idealized representation of the lines of **B** associated with the earth's magnetic axis and **RR** is its rotational axis.

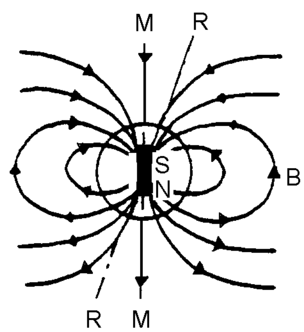


Figure 4.3 b) We can approximate the earth's internal magnetic field by imagining that a strong bar magnet is located at the center of the earth.

For computational purposes it is convenient to rewrite the equations for B_r B_λ and B in units of earth radii and the field on the surface of the earth at the magnetic equator B_{os}.

To do this consider a point for which $\lambda = 0$ and $r = R_\oplus$.

Then $B_r = 0$ and $B_\lambda = \frac{\mu_o m}{4\pi R_\oplus^3} = B_{os}$. We can use this relation to obtain:

$$\frac{\mu_o m}{4\pi} = B_{os}R_\oplus^3 \qquad \text{(Eqn. 4.4)}$$

putting this constant back into the equations for B_r B_λ and B we get:

$$B_r = -B_{os}R_\oplus^3\frac{2\sin\lambda}{r^3} = -B_{os}\frac{2\sin\lambda}{\left(r/R_\oplus\right)^3}$$

$$B_\lambda = B_{os}R_\oplus^3\frac{\cos\lambda}{r^3} = B_{os}\frac{\cos\lambda}{\left(r/R_\oplus\right)^3} \qquad \text{(Eqn. 4.5)}$$

$$B = B_{os}R_\oplus^3\frac{\sqrt{1+3\sin^2\lambda}}{r^3} = \frac{B_{os}\sqrt{1+3\sin^2\lambda}}{\left(r/R_\oplus\right)^3}$$

These equations express radial distances in units of earth radii. The constant B_{os} has a value of 31.3μT = 3.13 x 10^{-5}T.

The points at which the axis of our fictitious dipole magnet intersect the surface of the earth are known as the geomagnetic poles. In 1980 the geomagnetic north pole was located at 78.8° N and 70.9° W.

There also exists something called the magnetic pole which is the place where the field is vertical. This is a place on the surface which must be determined experimentally and is difficult to find.

An improved approximation to the measured geomagnetic field is obtained by displacing the dipole from the planetary center. The best fit is obtained by a displacement of 436 km in the direction 15.6° N and 150.9° E which is toward the Pacific Ocean. This approximation describes the measured geomagnetic field to an accuracy of 2 to 3% and is known as the Eccentric Dipole Model.

2 International Geomagnetic Reference Field

The standard model for the Earth's magnetic field is the International Geomagnetic Reference Field (IGRF). This field is specified in terms of standard tables of values which can be inserted into a mathematical model termed a multipole expansion. A brief discussion of this process is presented here - application is tedious and best done with a computer.

On the surface of the earth and upward for approximately 50 km the atmosphere can be considered to be an electrical insulator and therefore there are no currents flowing in that region. If the current i = 0 then we can define a magnetic potential U from which the magnetic field $\vec{B}$ can be derived

$$\vec{B} = -\nabla U .$$

Furthermore we can show that U must be a solution of Laplace's equation

$$\nabla^2 U = 0 .$$

If we use spherical coordinates (r, θ, ϕ) with the origin at the center of the earth and the polar axis along the rotational axis of the earth we can show that the form of U is an expansion of the form

$$\begin{aligned} U(r,\theta,\phi) &= \sum_{n=1}^{\infty} \sum_{m=0}^{n} \frac{r^n}{R_\oplus^{n-1}} \left(b_n^m \cos m\phi + c_n^m \sin m\phi\right) P_n^m(\cos\theta) \\ &+ \sum_{n=1}^{\infty} \sum_{m=0}^{n} \frac{R_\oplus^{n+2}}{r^{n+1}} \left(g_n^m \cos m\phi + h_n^m \sin m\phi\right) P_n^m(\cos\theta) \end{aligned} \qquad \text{(Eqn. 4.6)}$$

where $R_\oplus$ is the radius of the earth and P_n^m (cos θ) are the associated Legendre Polynomials (using Schmidt Normalization).

In the expression for U shown above, the first summation represents sources outside the earth (ionosphere and above) whereas the second summation represents sources internal to the earth. This is a powerful technique for separating these sources if we can determine the coefficients $b_n^m, c_n^m, g_n^m, h_n^m$ from actual measurements. Table 4.1 shows a recent set of coefficients derived from experimental measurements on the surface and magnetometers flown in low earth orbit.

Having obtained the proper expression for the potential U we still have to obtain the actual field components from $\vec{B} = -\nabla U$. If we define X, Y and Z as the north, east and vertically down components of $\vec{B}$ we obtain

$$\begin{aligned} X &= -B_\theta = \frac{1}{r}\frac{\partial U}{\partial \theta} && \text{"North"} \\ Y &= B_\phi = -\frac{1}{r\sin\theta}\frac{\partial U}{\partial \phi} && \text{"East"} \quad \text{(Eqn. 4.7)} \\ Z &= -B_r = \frac{\partial U}{\partial r} && \text{"Down"} \end{aligned}$$

where r increases outward, θ increases southward, and ϕ eastward in the usual arrangement for spherical coordinates.

The IGRF not only yields accurate (better than .5%) data for the field components at any point on or just above the surface of the earth, but it has also evaluated the contribution of external sources to the total field. We conclude that not more than a few tenths of a percent of the field intensity is due to sources external to the earth.

n	m	g	h	dg/dt	dh/dt	n	m	g	h	dg/dt	dh/dt
1	0	-29988		22.4		8	0	20		0.8	
1	1	-1957	5606	11.3	-15.9	8	1	7	7	-0.2	-0.1
						8	2	1	-18	-0.3	-0.7
2	0	-1997		-18.3		8	3	-l1	4	0.3	0.0
2	1	3028	- 2129	3.2	-12.7	8	4	-7	-22	-0.8	-0.8
2	2	1662	-199	7.0	-25.2	8	5	4	9	-0.2	0.2
						8	6	3	16	0.7	0.2
3	0	1279		0.0		8	7	7	-13	-0.3	-1.1
3	1	-2181	-335	-6.5	0.2	8	8	-1	-15	1.2	0.8
3	2	1251	271	-0.7	2.7						
3	3	833	-252	1.0	-7.9	9	0	6			
						9	1	11	-21		
4	0	938		-1.4		9	2	2	16		
4	1	783	212	-1.4	4.6	9	3	-12	9		
4	2	398	-257	-8.2	1.6	9	4	9	-5		
4	3	-419	53	-1.8	2.9	9	5	-3	-7		
4	4	199	-298	-5.0	0.4	9	6	-1	9		
						9	7	7	10		
5	0	-219		1.5		9	8	1	-6		
5	1	357	46	0.4	1.8	9	9	-5	2		
5	2	261	149	-0.8	-0.4						
5	3	-74	-150	-3.3	0.0	10	0	-3			
5	4	-162	-78	0.2	1.3	10	1	-4	1		
5	5	-48	92	1.4	2.1	10	2	2	1		
						10	3	-5	2		
6	0	49		0.4		10	4	-2	5		
6	1	65	-15	0.0	-0.5	10	5	5	-4		
6	2	42	93	3.4	-1.4	10	6	3	-1		
6	3	-192	71	0.8	0.0	10	7	1	-2		
6	4	4	-43	0.8	-1.6	10	8	2	4		
6	5	14	-2	0.3	0.5	10	9	3	-1		
6	6	-108	17	-0.1	0.0	10	10	0	-6		
7	0	70		-1.0							
7	1	-59	-83	-0.8	-0.4						
7	2	2	-28	0.4	0.4						
7	3	20	-5	0.5	0.2						
7	4	-13	16	1.6	1.4						
7	5	1	18	0.1	-0.5						
7	6	11	-23	0.1	-0.1						
7	7	-2	-10	0.0	1.1						

Table 4.1 Spherical harmonic coefficients of the IGRF 1980.0 in nT and nT/year for time derivatives. Handbook of Geophysics and the Space Environment, Air Force Geophysics Laboratory, 1985.

Field Components: There are several field components which can be used to specify the geomagnetic field vector $\vec{B}$ at any point. In Figure 4.4 these components are illustrated. Any three will suffice to fix $\vec{B}$.

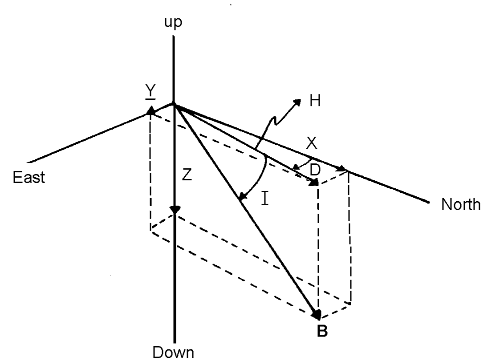


Figure 4.4

D = Declination (+ east from N)
H = Horizontal component
I = Dip Angle (+ down)
B = total Intensity
X = North-South component (+ North)
Y = East-West component (+ East)
Z = Vertical component (+ Down)

As an illustration of the results which cab be obtained from such a model, Figure 4.5 shows the magnetic field intensity at the earth's surface. The contours are in Gauss. One Gauss is 10^{-4} Tesla

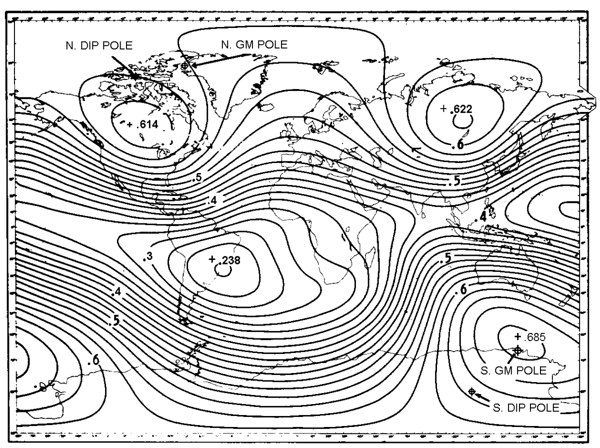


Figure 4.5: Map of total field intensity, B, for 1965 with locations of the dip poles and geomagnetic poles: units are Gauss (after Cain, et al, *J. Geophys. Res.*, 1965) Found in: Introduction to Space Science, edited by Wilmot Hess, 1965, The Earth's Magnetic Field, M. Sugiura and J. P. Heppner, page 13.

3 Magnetic Coordinate Systems

The centered dipole model may be used as the basis for a magnetic coordinate system in analogy with the geodetic coordinate system but rotated with respect to it. The geomagnetic poles were defined earlier as the penetration points of the dipole axis on the earth's surface. We can then define the geomagnetic equator as the great circle 90° from the geomagnetic axis. The geomagnetic latitude of a point is defined as the angle in a meridian plane subtended at the center of the earth between the point and the equator. Geomagnetic longitude requires an origin as Greenwich is the origin for geographic longitude.

The geomagnetic prime meridian is defined by the great circle which passes through both geomagnetic and through both geographic poles. Geomagnetic longitude is positive with respect to the geomagnetic prime meridian in eastern hemisphere. Geomagnetic time can be defined in a manner analogous to geographic time.

Transformation Equations from Geographic to Geomagnetic Coordinates:

As mentioned earlier the location of the north geomagnetic pole as of 1980 is 78.8° N and 70.9° W (= 289.1° E). If we call the geographic latitude λ and the geographic longitude ϕ we can express the transformation equations as follows

$$\sin\lambda_m = \cos\lambda_0 \cos\lambda \, \cos(\phi - \phi_0) + \sin\lambda_0 \sin\lambda$$

$$\cos\phi_m = \frac{\sin\lambda_0 \sin\lambda \, \cos(\phi - \phi_0) - \cos\lambda_0 \sin\lambda}{\cos\lambda_m} \qquad \text{(Eqn. 4.8)}$$

Where λ_m and ϕ_m are the geomagnetic latitude and longitude respectively and λ_0 and ϕ_0 are the geographic coordinates of the north geomagnetic pole.

Example:

Calculate λ_m and ϕ_m for Monterey whose geographic coordinates are 36.6° N and 121.9° W. (=238.1 °E)

$$\sin\lambda_m = \cos(78.8^\circ)\cos(36.6^\circ) \, \cos(238.1^\circ - 289.1^\circ) + \sin(78.8^\circ)\sin(36.6^\circ)$$

$$= 0.0981 + 0.5849$$

$$\sin\lambda_m = 0.6830 \quad \Rightarrow \quad \lambda_m = 43.1^\circ$$

$$\cos\phi_m = \frac{\sin(78.8^\circ)\sin(36.6^\circ) \, \cos(-51.0^\circ) - \cos(78.8^\circ)\sin(36.6^\circ)}{\cos(43.1^\circ)}$$

$$= \frac{0.4956 - 0.1158}{0.7304} = 0.52$$

ϕ_m = 58.7° or 360° - 58.7° = 301.3°

Thus the geomagnetic coordinates of Monterey are 43.l° N, 301.3° E.

4 Dynamo Theory of the Main Field

During the past 30 years the outlines of a general theory capable of explaining the essential features of the Main Field have emerged. Furthermore it is believed that this general approach will apply to any astronomical body for which the following three conditions are met

(1) The system must be large and have a high electrical conductivity.
(2) There must be some non-symmetric rotational or convective motion present.
(3) There must be an internal energy source available.

The liquid core of the earth appears to meet these criteria
(1) The outer core extends from a depth 2800 km to a depth of 5400 km and consists of liquid metals (92% Fe and about 8% Ni) and is believed to have an electrical conductivity of about 10^6 (Siemens).
(2) As a result of viscous forces and temperature gradients in the molten core there is both differential rotation and turbulent upwelling present. The secular changes in the geomagnetic field seem to confirm these assumptions.
(3) Several energy sources are potentially available in the core and specially in the inner core (below 5400 km). These are the energy generated by radioactive decay, by gravitational contraction and possibly energy released by high pressure phase transitions.

The details of the magneto hydrodynamic theory are still quite uncertain as well as very complex. We shall therefore give only a qualitative description of the major points of the theory.

We may visualize the generation of the main geomagnetic field something like this: A field line of external origin (perhaps due to the solar or galactic field is "frozen" into the highly conducting core of the earth and due to rotation of the core is wound up into a strong (.05T or 50 Gauss) azimuthal field as illustrated in Chapter 1. By a series of complex motions associated with turbulent upwelling this azimuthal field is carried outward and converted into a toroidal helical field and an associated azimuthal current system which in turn generates the observed dipole field of the earth .

Although many aspects of this theory are still quite speculative, considerable support for the general concept comes from solar observations. On the sun there is no solid mantle and hence the azimuthal field is directly observable on the surface of the sun. This "dynamo theory" is able to explain at least in principle the geologically documented reversals of the geomagnetic field. These reversals are believed to be caused by the interactions of two or more "dynamos" operating within the core.

Finally it should be noted that the theory actually describes a "flux amplification" process in which energy from an internal source is used to amplify a weak seed field into a much stronger dipole field. This mechanism is believed to be active in all astronomical bodies (planets, stars, galaxies) which satisfy the original conditions stated above. The ultimate source of the seed field must of course be an electric current and a number of processes are available to generate such initial currents.

C Time Variations of the Geomagnetic Field

The Main Field which we discussed so far shows very slow time variations both in magnitude & direction, characteristic times being on the order of thousands of years. These so-called "secular variations" are of geologic origin and result among other things in the well known variations of magnetic north with respect to geographic north (variation of declination)

1 Diurnal Variations

When continuous records from magnetic observatories are examined the three magnetic field components show variations which are repeated every day, mostly during the daylight hours. The pattern of each vector variation also changes systematically with latitude on a global scale, as shown in Figure 4.6.

Analysis shows that about two thirds of the variations are due to sources external to the earth and one third appears to be due to internal sources. However the internal sources are the result of electric currents induced within the earth by external time varying magnetic fields. Thus all of the variations are directly or indirectly due to external sources.

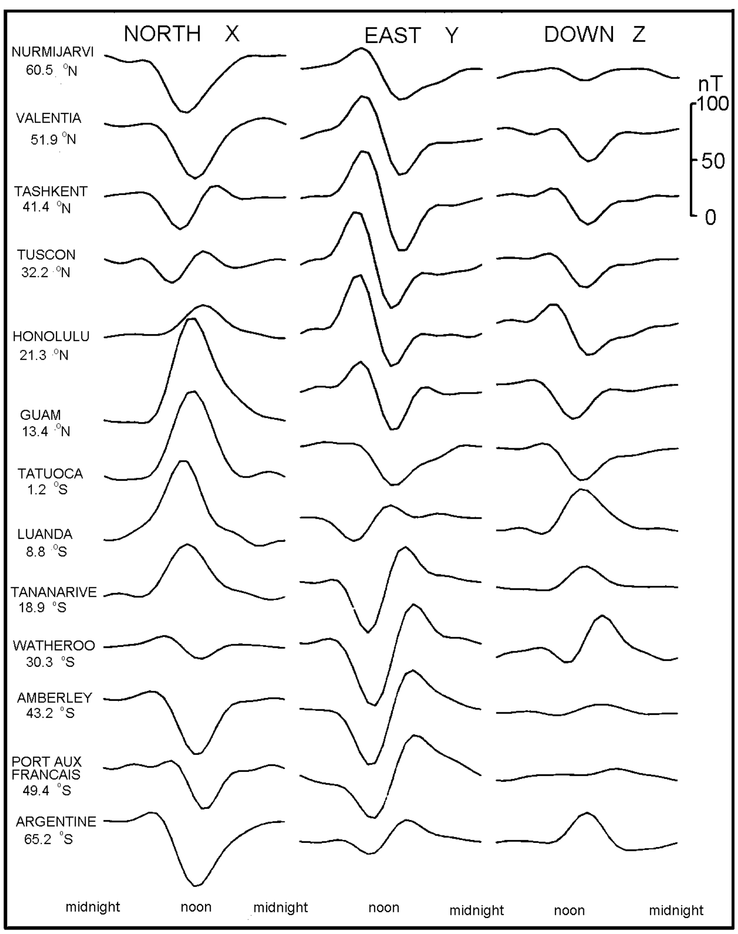


Figure 4.6 Diurnal variation curves as a function of local solar time for observatories at various (geographic) latitudes.
From: Introduction to Geomagnetism, W. D. Parkinson, page 262.

Ionospheric current systems are responsible for the daily variations. Convective movements of the conducting upper atmosphere across the earth's magnetic field produce electric currents in the medium (ionosphere). The large scale motions of the upper atmosphere occur because of pressure and temperature differences brought about by solar heating, tidal forces and the Coriolis force. This complex mechanism is usually referred to as the atmospheric dynamo. An idealized current system for the generation of the observed daily variations is shown in Figure 4.7

Strong currents in the system are mostly found on the sunlit side of the earth and in the region between the equator and mid latitudes. In each hemisphere there is a vortex of current with its center at about 30° geomagnetic latitude and near the noon meridian. The current rotates counterclockwise in the northern hemisphere and clockwise in the southern hemisphere. Although the current densities are quite low the total circulating current is about 120,000 A. This current system is fixed relative to the sun-earth line and as a given point on the surface rotates under it the magnetic field of the overhead currents gives the variations shown in Figure 4.6.

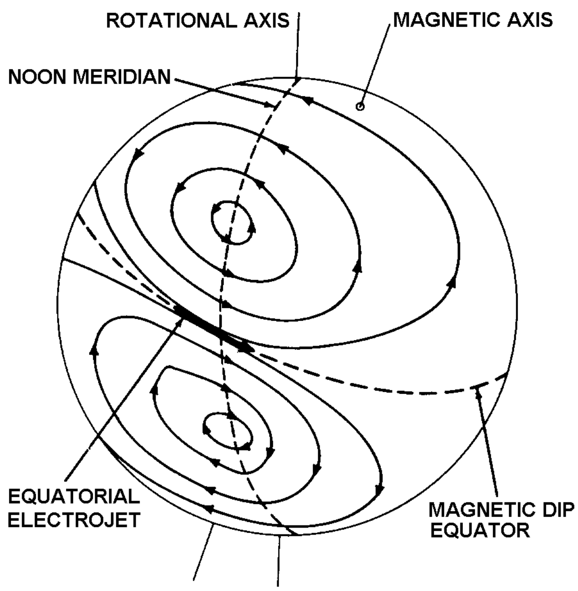


Figure 4.7 Currents flow in the upper atmosphere (ionosphere) as shown schematically, in the directions indicated by the arrows.

2 Magnetic Storms

Intense, worldwide transient variations of the geomagnetic field are called magnetic storms. They are frequently accompanied by other phenomena such as intense auroral displays, ionospheric disturbances, etc.

The frequency of magnetic storms correlates closely with the solar sunspot cycle leading to the conclusion that magnetic storms on earth are caused by solar events. The cause of magnetic storms is the arrival of a solar plasma pulse ejected from the sun during a solar flare. The plasma traveling at ~1000 km/sec reaches the earth a day or two after the occurrence of the flare. What we describe as a magnetic storms is the result of the interaction of the solar plasma with the earth's magnetosphere. Most magnetic storms undergo a pattern of development such as that indicated in Figure 4.8.

The start of a typical storm is marked by an abrupt increase in the horizontal component (H) known as the sudden commencement (SC) of the storm. The increase is typically 30-50 nT world-wide in a matter of a few minutes. The effect is the result of the impact of the plasma pulse traveling at several times the ordinary solar wind velocity on the outer boundary of the magnetosphere. The compression of the boundary is transmitted in the form of magneto hydrodynamic waves and is seen on the surface of the earth as an increase in the ambient field strength.

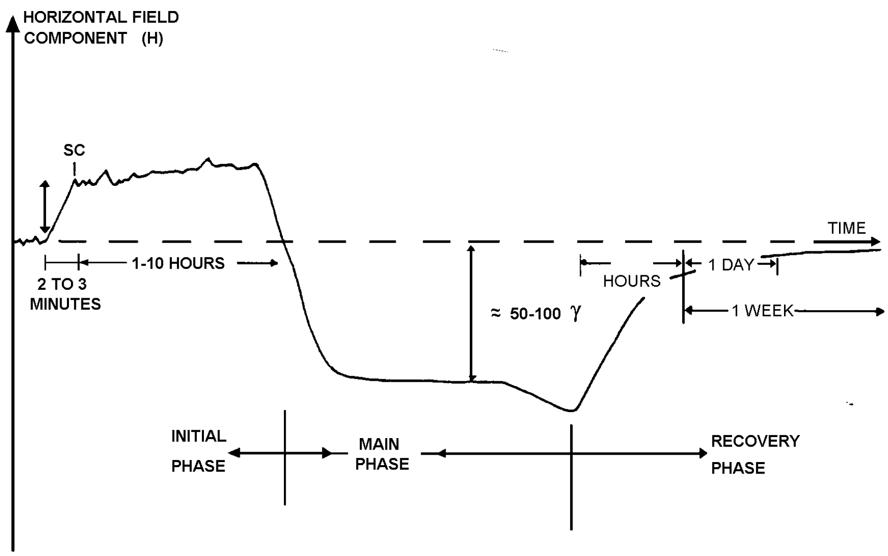


Figure 4.8 Example of magnetic field measurements during a magnetic storm. The baseline (horizontal axis) represents mean magnetospheric conditions. The symbol Sc is used to denote the start of the sudden commencement which typically has an intensity of 5 - 30 gammas (γ) (or nano-Tesla, nT). Prochaska, 1980).

For the next 2-10 hrs. the horizontal field component remains above its undisturbed value. This interval is known as the initial phase of the storm and corresponds to a compressed state of the magnetosphere. This new equilibrium state persists until the bulk of the plasma has passed the earth on its outward flow through the solar system.

Meanwhile the main phase of the storm lasting 12 to 24 hrs. is initiated: H decreases to values typically 100 nT below prestorm values. This decrease is the result of a westward ring current induced in the magnetosphere by the compression during the initial phase. The ring current is composed of newly trapped particles (both electrons & protons) as well as acceleration of particles previously present in the magnetosphere at altitudes of several earth radii. During the final stage of the storm lasting several days the ring currents gradually dissipate and the field returns to its prestorm value.

Individual storm records show great irregularities as compared to the "typical" pattern of Figure 4.8. The initial and main phase tend to be very noisy and large amplitude fluctuations occur with periods as long as 30 minutes. Storm records in the auroral and polar regions are particularly noisy as indicated in Figure 4.10 which shows a storm record at 4 magnetic latitudes. Note also the difference in the scales on left side of the graph.

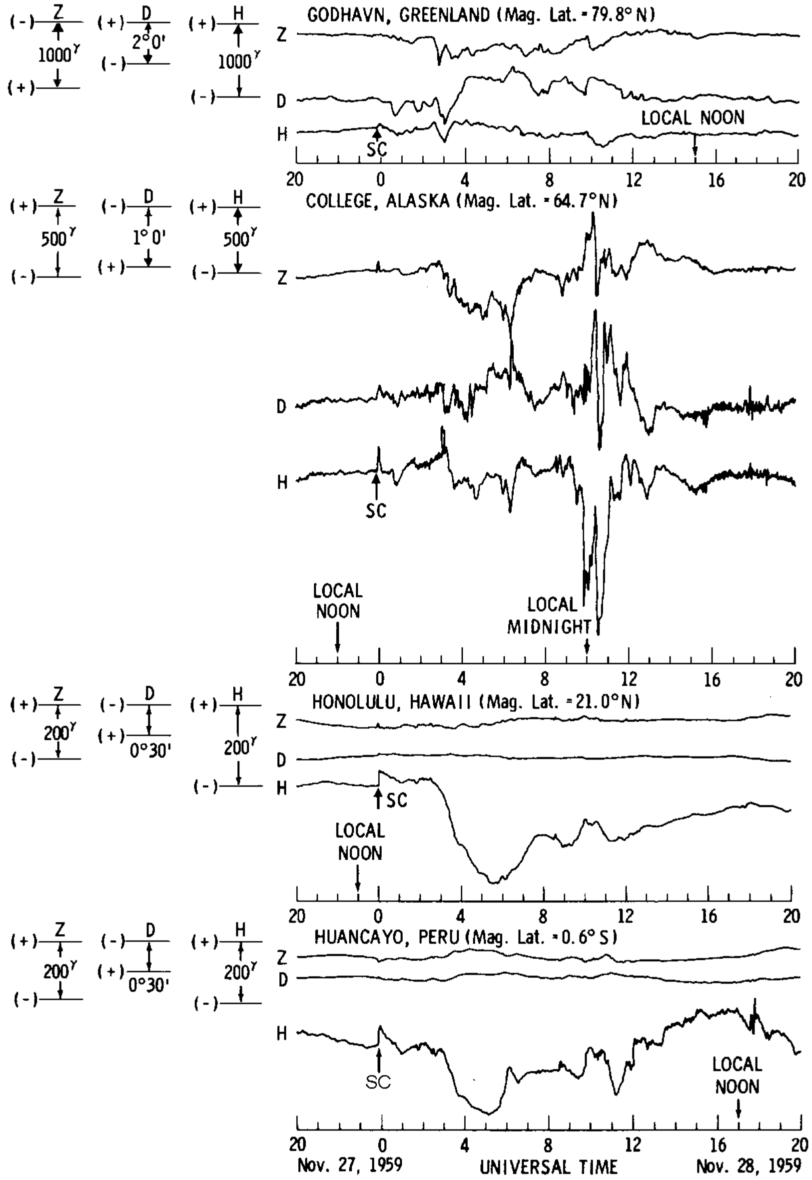


Figure 4.9 Examples of magnetic storm of moderate intensity as recorded at different latitudes. H, D, and Z are the symbols for the three components of the magnetic field, Horizontal, Declination, and Vertical, respectively.
From: Introduction to Space Science, edited by Wilmot Hess, Chapter 1, the Earth's Magnetic Field, by M Sugiura and J. P. Heppner, page 59, 1965.

Not all solar flares (or CME's) produce magnetic storms on earth. The actual trajectory which a given plasma pulse follows after leaving the sun is generally quite complex. The question of whether or not it will reach the earth depends upon where it leaves the sun, and then more subtle problems involving the transport of plasma. The resulting transport pattern is sufficiently complex that it is not presently possible to predict whether the plasma stream from a given flare will hit or miss the earth.

3 Magnetic Indices

A large number of indices have been devised to characterize the state of activity of the geomagnetic field or some portion of it. Most of these indices are highly specialized and will not be discussed here. However two of them, the K and Dst indices, have general use and we shall have a look at them:

The K index is an indicator of the general level of activity in the magnetic field, at mid to high latitudes. As such, it is often used as an indicator of auroral activity, and the level of magnetic activity at geosynchronous orbit.. Each observatory assigns a digit between 0 and 9 for each 3 hr. interval starting at 0^h (UT) to each of the three field components (X, Y, Z or H, D, Z usually). The largest deviation from the average is used and normalized on a quasi-logarithmic scale. This means that each observatory chooses an appropriate scale so that the frequency of a given K number is the same at all observatories. Thus 350 nT may correspond to K = 9 at one observatory but for another station K = 9 corresponds to 1000 nT.

Each K value represents roughly a factor of 2 increase in the magnitude of the excursion. It has also become customary to subdivide each value on the K scale in to 3 sub-steps by the subscripts -, 0 and +. Thus we have
---- 4_-, 4_0, 4_+, 5_-, 5_0 ----

The planetary index K_P is obtained by averaging the standardized K values from 12 observatories located between 48° and 63° geomagnetic latitude. Figure 4.10 shows a typical magnetogram, and the K value which would correspond to each level of magnetic field fluctuation. The K value for the Fredricksberg, VA observatory is often used as a "local" index for the continental US. It is important to note that since we are averaging a set of observations taken three hours apart we cannot get any information about higher frequency oscillations i.e., for f > 1/(3x3600) ~ 10^{-4} Hz

Diagrams of K_p are typically made for long periods as illustrated in Figure 4.11. Note that the horizontal axis is 27 days - one solar rotation. Can you see the periodicity?

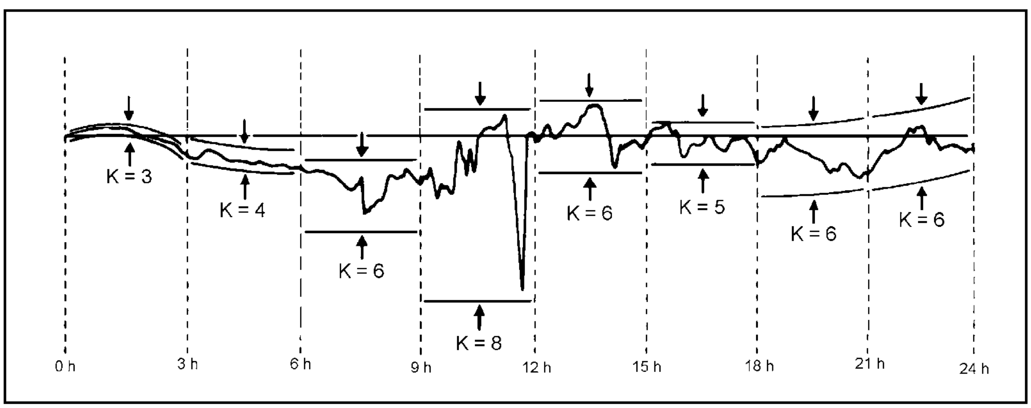


Figure 4.10 A typical magnetogram (H trace only) showing the ranges corresponding to the K-indices assigned to each 3-hour interval for that day.
From: Introduction to Geomagnetism, W. D. Parkinson, page 284.

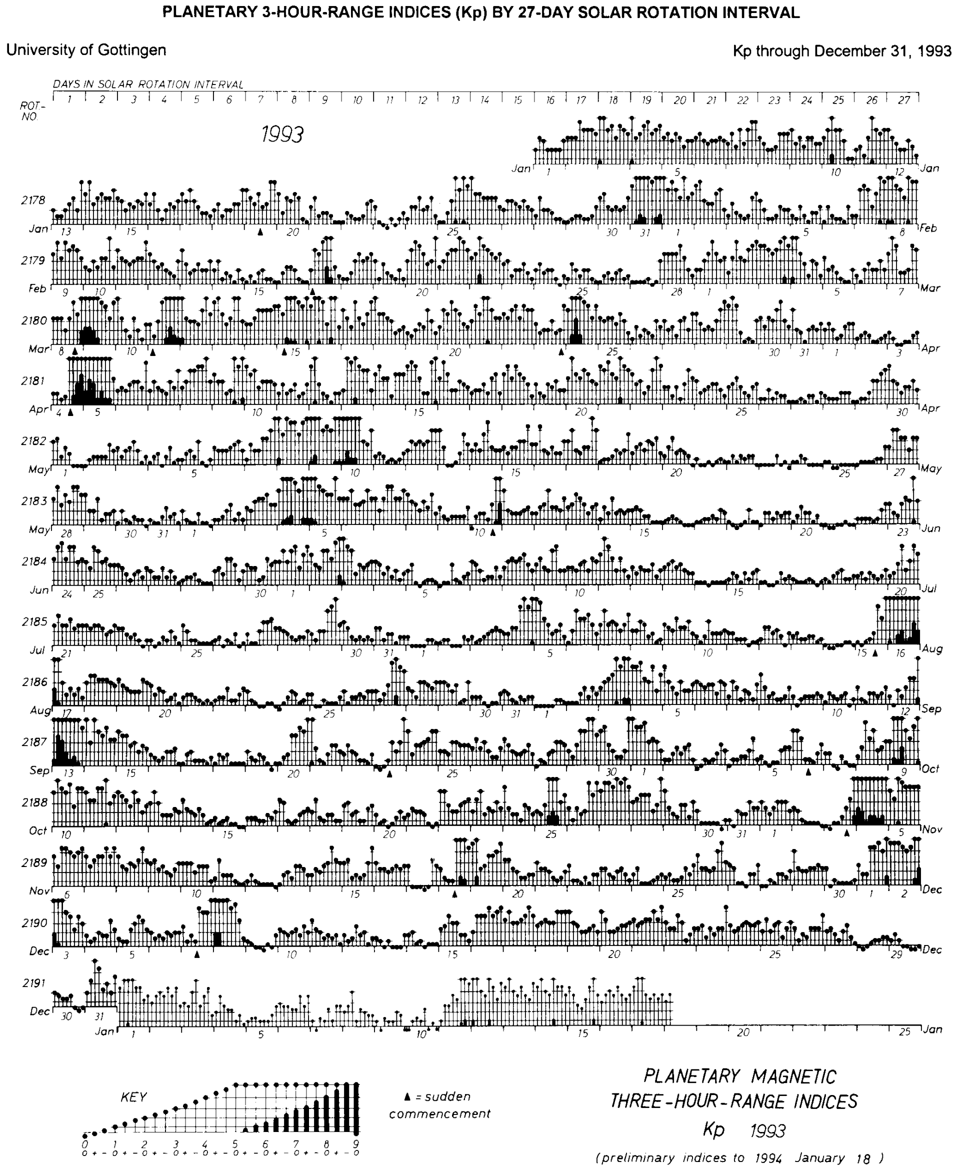


Figure 4.11 Kp figures for one year

A practical measure for the overall strength of the extraterrestrial ring current is the D_{ST}-index which measures the middle latitude spatially averaged decrease in the horizontal component H of the earth's surface magnetic field $D_{ST} = \langle D_H \rangle$. Under this definition the quiet time ring current corresponds to $D_{ST} = 0$. Hourly values of D_{ST} index are published by NASA National Space Science Data Center, Goddard Space Flight Center, Maryland. Magnetic storms generally have D_{ST} depressions on the order of 100 to 200 nT (very large storms may exceed D_{ST} = 300 nT), and the D_{ST} index may also fluctuate substantially for other geomagnetic conditions for which D_{ST} generally remains less than 50 nT. Figure 4.12 shows an example of the D_{ST} index plotted for June - December 1972, and the occurrence of four magnetic storm periods in June, August, September and October/November is evident. Note the corresponding increase in auroral activity, as revealed by the periods of high Kp (Kp > 5).

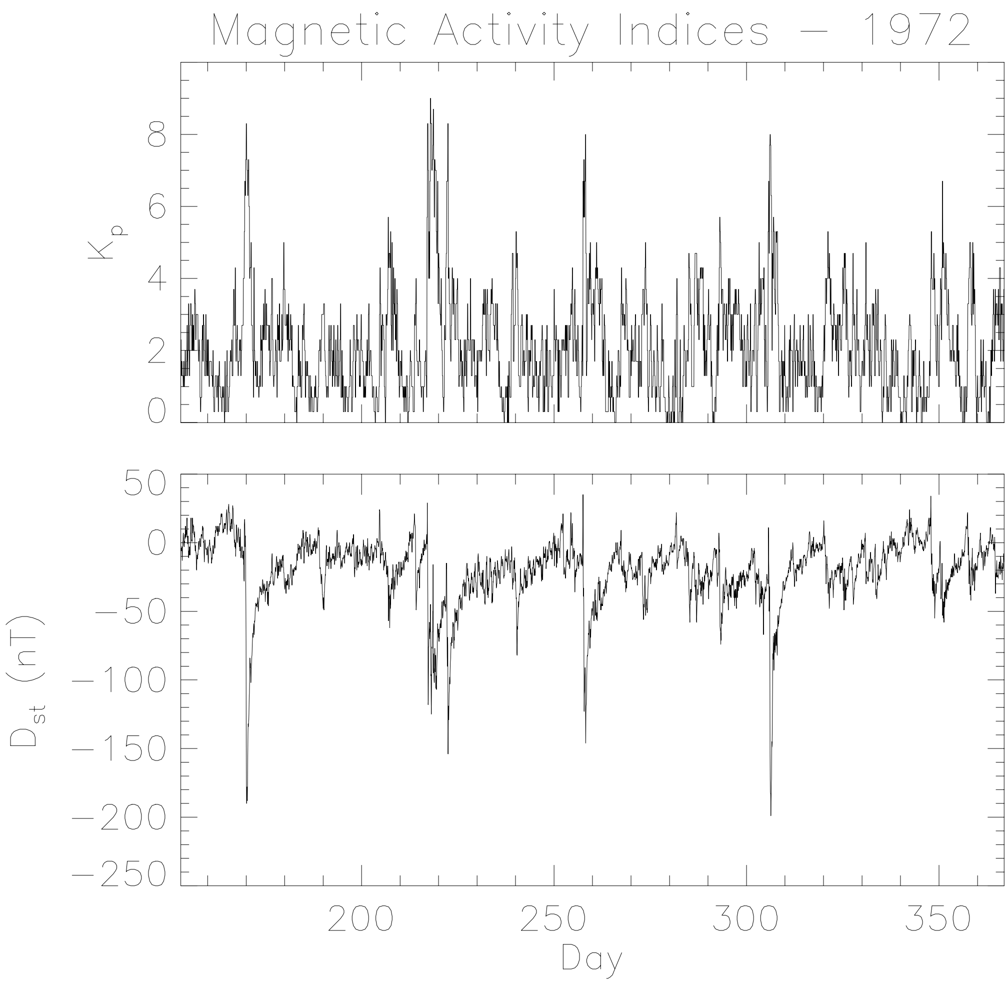


Figure 4.12 Magnetic Activity Indices

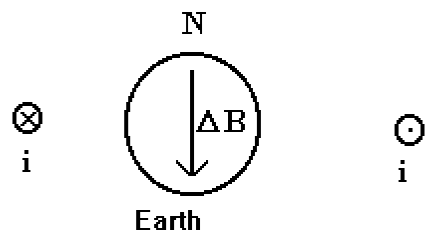
D References

Nishida, A. (1978). Geomagnetic Diagnosis of the Magnetosphere. Springer-Verlag, N. Y.

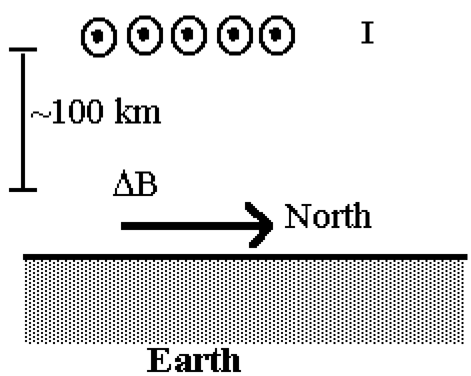
Parkinson, W. D., Introduction to Geomagnetism, Elsevier Science Pub Co., Inc., NY, NY

E Problems

1. The activity index, Dst, can reach ~100 nT. Estimate the current necessary to produce this magnetic field effect. Assume the current is a "ring" around the earth, at 3 R_E. That is, if $\Delta B \sim 100$ nT, use the Biot-Savart law for a loop to estimate the current, i.. To keep life simple, assume that the standard formula (e.g. Halliday and Resnick) for the field at the center of a ring is reasonably close to the formula for the field off the axis (e.g. the surface of the earth).



2. The diurnal current variations are due to currents flowing in the upper atmosphere (ionosphere). Take this current to be an infinite, planar (e.g. sheet) current. How large a current density is needed to produce a 100 nT perturbation (ΔB)?



3. Find the magnetic latitude and longitude of Diego Garcia. Find both components of the local magnetic field there.